A REVIEW OF 'B'-PILLAR AND FRONT SEAT BELT LOADS MEASURED IN ANCAP OFFSET FRONTAL CRASH TESTS.

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ABSTRACT

The ANCAP (Australian New Car Assessment Program) have been conducting offset frontal crash tests into a deformable barrier since 1995. During this time the results of the ANCAP tests have shown significant improvements in occupant protection measured via reduction in dummy injury measurements, i.e. HIC, chest 'g', etc.

Occupant protection has improved with manufacturers designing structures to minimise the occupant space intrusion with the aim to have the crash energy absorbed by deformation of the frontal vehicle structure. Also new restraint technology has been included along with the vehicle structure designed to optimise the restraint technology.

This paper will review crash tests measurements to evaluate if changes in vehicle structures and restraint technology have changed the loads in either the occupant compartment or on the front seat belts.

ANCAP measure the 'B' pillar accelerations and also the front seat occupant seat belt loads. The maximum accelerations and time recorded for the right (driver) hand side 'B' pillar was used to represent the loads on the passenger compartment. The seat belt loads that are used in the paper are the maximum loads on both the sash and lap sections of the driver's three point seat belts.

The analysis showed that while the dummy injury measurements have reduced there has not been a corresponding reduction in either 'B' pillar accelerations or seat belt loads.

INTRODUCTION

From 1995 ANCAP included a 40 % offset frontal crash into a deformable barrier in accordance with the test protocols developed by the EEVC in 1993. This test was initially conducted at 60 km/hr, which was the speed for the proposed European regulations.

However, ANCAP increased the crash test speed to 64 km/hr to be consistent with both the US IIHS who also started conducting consumer crash tests at this speed in 1995 and the developing Euro NCAP program.

This study has used the results of 49 passenger cars tested by ANCAP. For the high volume sellers ANCAP has tested up to 4 different model years of some makes.

The dummy injury measurements have improved from over 1000 HIC and 44 mm of chest deflection to less than 300 HIC and 21 mm of chest deflection.

ANCAP has conducted some offset frontal crashes with off-road 4 wheel drive passenger cars and also light utilities. The results from crash tests of these vehicles have not been included in this study.

B-PILLAR PEAK ACCELERATIONS

The initial part of this paper examines the B-pillar peak accelerations for the driver's side of the vehicle measured during the ANCAP tests see Table A1.

The driver's side B-pillar accelerations are used for an indication of the acceleration experienced by the occupant compartment. The driver's side is chosen as the driver's side of the vehicle impacts the deformable barrier in the offset frontal test, generating higher loads than the passenger's side.

In the offset frontal test a tri-axial accelerometer is mounted on both the driver's and passenger side of the vehicle at the base of the B-pillar near the seat belt anchorage.

For the assessment of B-pillar performance the longitudinal acceleration, Gx, was chosen as this was consistently measured by ANCAP since 1995. Additionally, Gx should give an indication of the performance of the vehicle's structure.

During 1999 the resultant B-pillar acceleration was calculated. This showed that Gx was the dominant factor in the resultant B-pillar acceleration in terms of both peak acceleration and time. Unfortunately, this data was not available for all the vehicles included in this study.

To determine if there was any variation in vehicle structural performance that may result in any significant variation in driver's side B-pillar peak acceleration an analysis of the results was undertaken. Gx was plotted against both year of manufacture of the tested vehicle and also the test mass.

The graph of vehicle test mass vs. Gx, Figure 1, showed a scatter around a line that trended upwards from approximately 30g at 1050kg to approximately 37g at 1850kg.

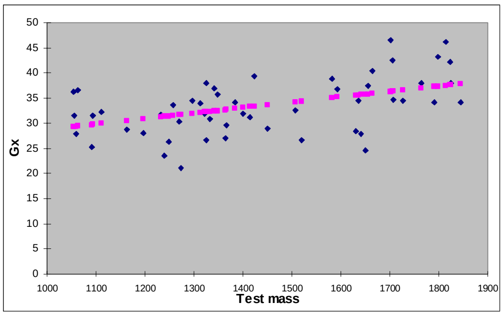

Figure 1. Test mass vs. Gx

Similarly, the plot of YOM against Gx, Figure 2, also showed an upward trend.

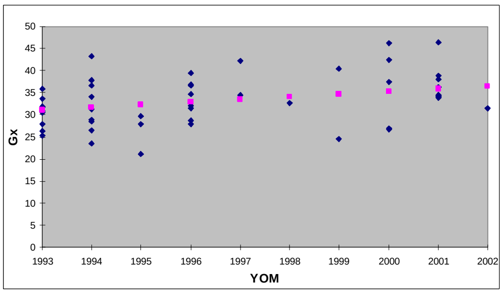

Figure 2. YOM vs. Gx

A regression analysis was conducted with the following results:

- Gx vs. YOM, $r^2 = 0.1172$
- Gx vs. test mass, $r^2 = 0.2291$

While the graphs both showed an upward trend the regression analysis did not show any significant correlation between Gx and YOM or test mass

A similar analysis was conducted using the time of max acceleration, t_{max}, plotted against both year of manufacture and test mass.

The plot of test mass vs. t_{max} , Figure 3, showed a slight upward trend while the plot of YOM vs. $t_{max,}$ Figure 4, showed a downward trend.

A regression analysis was conducted with the following results;

- t_{max} vs. YOM, $r^2 = 0.0244$
- t_{max} vs. test mass, $r^2 = 0.0436$

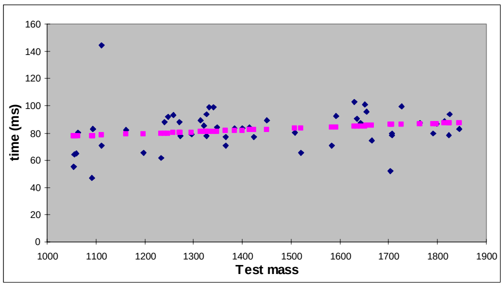

Figure 3. Test mass vs. t_{max}

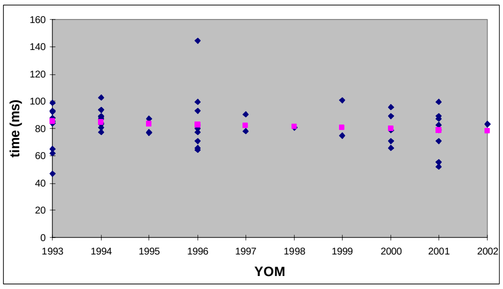

Figure 4. YOM vs. t_{max}

A review of the high-speed film of some tests indicates that the Gx occurred when the test vehicle bottomed out on the barrier. This is more prevalent with the larger cars.

The analysis conducted did not show any significant change in B-pillar accelerations, or time of maximum acceleration with either YOM or mass of test vehicle.

VEHICLE CATEGORIES

As there was not any significant change due to either YOM or test mass when considering all 49 vehicles the data was reviewed by vehicle category, i.e. large, medium and small. These are the test categories used by ANCAP and are based on vehicle mass.

The mean and standard deviation of grouped YOM for each of the three categories were calculated. The main limitations of the large and medium car categories are the low numbers in each YOM grouping. Any review of results will need to take this into account.

Table 1 showed that there was a small decrease in test mass for later YOM without any significant change in either maximum Gx or time of maximum Gx for the large cars.

Table 1.
Large Cars

YOM		Mass (kg)	Gx max (g)	t_{max} (msec)
00/01	mean	1741	39.3	86.5
4 vehs	s	44.7	6.1	9.7
96/97	mean	1795	38.5	79.0
2 vehs	s	78.9	5.3	1.3
94[1]	mean	1811	40.6	90.4
2 vehs	s	19.1	3.8	4.9
All	mean	1783	39.4	85.6
9 vehs	s	56.0	4.7	8.0

The analysis of medium cars, summarised in Table 2, showed that there was an increase in test mass with the newer vehicles. This corresponded to a decrease in maximum Gx (for 64 km/hr tests). There was no corresponding change in time of maximum Gx for this group.

Table 2.
Medium Cars

YOM		Mass (kg)	Gx max (g)	t_{max} (msec)
99/00	mean	1652	31.1	98.3
2 vehs	s	3.5	9.2	3.9
97/98	mean	1602	35.9	81.8
3 vehs	s	83.2	4.1	7.9
95/96	mean	1552	34.8	85.8
3 vehs	s	114	6.0	7.8
94[1]	mean	1444	31.7	90.6
2 vehs	s	113	3.8	7.8
All	mean	1538	33.2	88.7
9 vehs	s	120.7	4.9	8.6

The test mass of the small cars, results summarised in Table 3, varied with the standard deviation of some YOM groupings greater than 10 % of the mean test mass.

However, the maximum Gx did not vary significantly, except for the 95/96 grouping, which had a single vehicle with a maximum Gx of 111.5g and a time of maximum Gx of 144.5msec.

If this test was ignored the mean Gx max for 95/96 models was 29.7g and t_{max} was 76.7msec. The results would then be consistent in mean Gx max with a decrease in t_{max} for the small car groupings shown.

A regression analysis conducted on the small car results showed that the best correlation was between test mass and time of peak acceleration. However, this was still not a significant correlation with $r^2 = 0.1925$

Table 3.
Small Cars

YOM		Mass (kg)	Gx max (g)	t_{max} (msec)
00-02	mean	1273	31.7	73.8
6 vehs	s	174	4.0	12.4
95/96	mean	1202	39.9	85.2
8 vehs	s	114	29.3	26.4
94[1]	mean	1230	30.2	82.4
4 vehs	s	132	6.2	4.6
93[1]	mean	1240	30.4	79.4
9 vehs	s	102	3.4	17.5
All	mean	1239	34.2	82.3
	s	124	15.4	15.0

Note: 1 denotes models tested at 60 km/hr in Tables 1, 2 and 3.

SELECTED MODELS

While the above analysis did not show any change in B-pillar measurements there has been a consistent reduction in dummy injury measurements, HIC and chest deflection, during the time ANCAP has been conducting offset frontal crash tests.

The next stage in the review was to examine in more detail a number of vehicle models to review the driver B-pillar measurements, driver seat belt loads and driver dummy injury measurements over different model years.

A comparison of the B-pillar acceleration trace, Gx, for each vehicle model was conducted. However, the different crash test speeds of the early tests and different vehicle masses make this difficult.

The results were also used to calculate the change in kinetic energy over the previous 5 milliseconds (msec), i.e.

$$\Delta KE = ½\, m.\ \Delta\, v^2 \qquad (1).$$

$$\text{Where, } \Delta v = \Delta a/5\text{msec} \qquad (2).$$

The data was corrected to align the start point of each crash. The Gx data up to 120 msec was then used to calculate the change in energy. 120 msec was chosen as the final point in this analysis as the vehicles had completed the crash at this point. Any velocity changes after completion of the forward crash is ignored for this calculation.

Five different vehicles have been chosen: General-Motors Holden Commodore, Ford Falcon, Toyota Camry, Toyota Corolla and General Motors-Holden Barina.

General Motors-Holden Commodore

ACNAP has tested 3 model years of Commodore: 1994, 1997 and 2000. ANCAP plan to test the 2002 model year Commodore but the results are not available at the time of preparing this paper.

The 1994 Commodore was tested at 60 km/hr and contained seat belt webbing grabbers and a driver's airbag.

The 1997 Commodore was tested at 64 km/hr. This model was heavier than the previous Commodore while having a similar wheelbase and similar occupant protection package. The 1997 Commodore had an improved front structure, driver's airbag and seat belt webbing grabbers and pre-tensioners.

The 2000 model was again tested at 64 km/hr and had a driver's airbag and seat belt pre-tensioners. The 2000 model had a longer wheelbase and was higher than the 1997 model.

The B-pillar acceleration graphs showed similar acceleration traces with the peak acceleration of the 1994 test more than 10g lower than the 1997 model as the 1994 test was conducted at 60 km/hr.

The ΔKE graph, figure 5, showed the test on the 2000 model started with slightly less energy than the 1997 model test and maintained that difference throughout the test until the peak acceleration was reached. The 2000 model impacted 0.4 km/hr slower and was 62 kg lighter.

Table 4
Commodore driver results

YOM	Lap belt load (kN)	Sash belt load (kN)	HIC	Chest (mm)
2000	6.55	7.7	537	39.9
1997	7.01	-	510	36
1994	5.84	12.89	730	39

Note: '-' in Tables 4 to 8 indicates no result available from the test report.

Even though the 1994 model had the lowest peak Gx, due to the lower crash test speed, it had the higher HIC. The maximum lap belt loads were higher for the later tests and while the maximum sash belt load in the 1994 test was significantly higher than the 2000 test.

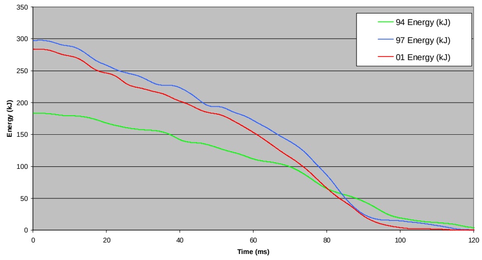

Figure 5. Commodore ΔKE

Ford Falcon

ANCAP have tested 3 model year Falcons; 1994, 1997 and 2001. ANCAP plan to test the 2002 model year Falcon but the results are unavailable at the time of writing.

The 1994 Falcon was tested at 60 km/hr and had a driver's airbag and seat belt webbing grabbers. The 1997 Falcon was a facelift without any additional safety features. This model was tested at 64 km/hr.

The 2001 model was a new vehicle and contained driver's airbag, seat belt pre-tensioners and webbing grabbers. This model was a similar size and mass to the 1997 model.

The maximum Gx, HIC and chest deflection of both the 1994 and 1997 models were similar even though the 1994 model was tested at 60 km/hr. Maximum Gx occurred slightly later in the 1994 test.

The different test speed and later maximum Gx, are shown in the ΔKE graph, figure 6, where the energy curves for the two tests are similar and begin to converge toward the time of maximum Gx.

It is difficult to use the data from the 2001 model test for a comparison as the seat belt loads were not available. Also, the acceleration trace shows a number of peaks prior to the maximum Gx that are not consistent with the other two tests.

The test report did not contain any explanation for multiple peaks.

Table 5
Falcon driver results

YOM	Lap belt load (kN)	Sash belt load (kN)	HIC	Chest (mm)
2001	-	-	381	26
1997	4.55	7.43	636	36
1994	4.29	8.41	600	35

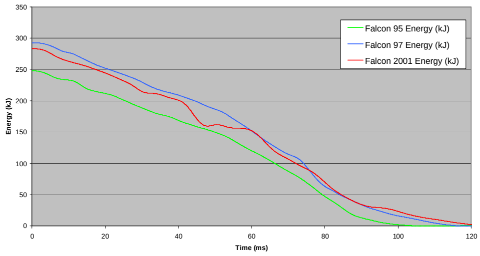

Figure 6. Falcon ΔKE

Toyota Camry

ANCAP have tested 4 model Camry's; 1994, 1995, 1997 and 2000. ANCAP plan to test the 2002 model year Camry but the results are unavailable at the time of writing.

The 1994 model Camry was tested at 60 km/hr. The 1995 model was the same as the 1994 model but was tested at 64 km/hr.

The 1997 model Camry was a new vehicle that was slightly larger and heavier than the earlier models. The 2000 model was the same as the 1997 model. The 2000 model had a driver's airbag as standard equipment. The 1997 model was not tested with a driver's airbag, which was optional.

The acceleration traces show that the maximum Gx of the 1994 and 1995 tests were similar. However, the time of maximum Gx of the 1994 test was later. The maximum seat belt loads were also similar, while the 1995 test conducted at the higher test speed had higher dummy injury measurements.

Table 6.
Camry driver results

YOM	Lap belt load (kN)	Sash belt load (kN)	HIC	Chest (mm)
2000	7.83	5.74	768	35.7
1997	4.77	7.48	700	45
1995	5.09	5.97	835	40
1994	5.48	5.22	640	37

The acceleration traces of the 1997 and 2000 models were also similar. However, the maximum seat belt loads were significantly different with a higher lap belt and lower sash belt maximum load in the air bag equipped 2000 model. The HIC's were similar while the chest deflection was lower in the 2000 model test.

Again the ΔKE graph, figure 7, showed similar curves for all three crashes taking into account the lower test speed of the 1994 test. The graphs for tests of the 2000, 1997 and 1995 models overlay each other.

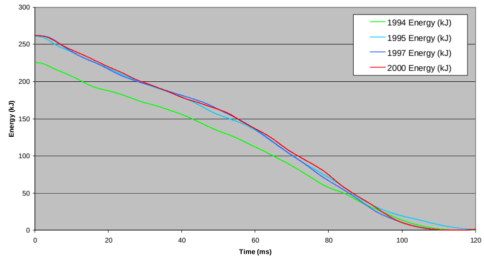

Figure 7. Camry ΔKE

Toyota Corolla

ANCAP have tested 3 model Toyota Corolla's; 1993, 1994 and 2002.

Both the 1993 and 1994 models were tested at 60 km/hr. Both models had similar test masses and while a driver's airbag was available neither vehicle included the airbag.

The 2002 model was smaller then the previous models, i.e. shorter wheelbase and lighter. Also the 2002 model came standard with driver's airbag and seat belt pretensioners.

The acceleration traces, and also energy graphs for both the 1993 and 1994 models were very similar. While the 1993 model had a higher peak Gx, the duration of the peak loading was similar for both models.

Also the maximum seat belt loads were similar. However, the dummy measurements on the 1994 model were higher than the 1993 model.

Table 7.
Corolla driver results

YOM	Lap belt load (kN)	Sash belt load (kN)	HIC	Chest (mm)
2002	7.5	5.83	218	26.5
1994	6.37	6.22	1240	53
1993	6.53	6.16	1020	48

The lap belt load in the 2002 model test was higher and the sash belt load was lower than the previous tests with substantially reduced dummy HIC and chest deflection.

The test on the 2002 model resulted in higher maximum Gx and ΔKE, however, the graphs followed a similar curve to the earlier tests.

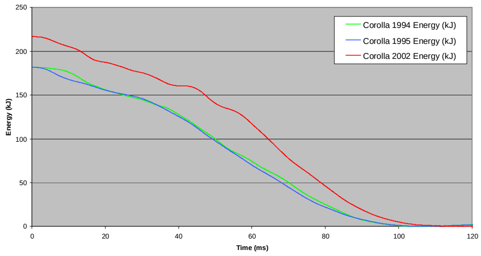

Figure 8. Corolla ΔKE

General Motors-Holden Barina

ANCAP have tested 4 model Barina's; 1993,1994, 1996 and 2001. Both the 1993 and 1994 models were tested at 60 km/hr, while the 1996 and 2001 models were tested at 64km/hr.

The B-pillar acceleration data was not available for the 1994 model, however, the peak seat belt loads and dummy injury measurements were.

The Barina models increased in mass over the years and the 1996 and 2001 models had driver's airbags as standard equipment while the 1993 and 1994 models did not.

When the Gx traces were converted to ΔKE, figure 9, the 1996 and 2001 model Barina's had similar traces, however, the 1993 model energy curve was significantly different. The 1993 model energy curve was flatter then both the 1996 and 2001 Barina's.

The maximum seat belt loads for the 1993 model were very low and the HIC and chest deflection for the driver dummy high. The other models had higher maximum seat belt loads, more in line with the other vehicles considered, and the HIC's and chest deflection also were lower.

Table 8.
Barina driver results

YOM	Lap belt load (kN)	Sash belt load (kN)	HIC	Chest (mm)
2001	6.66	7.07	431	28
1996	5.38	4.90	307	21
1994	6.33	6.91	620	33
1993	3.57	3.22	1210	44

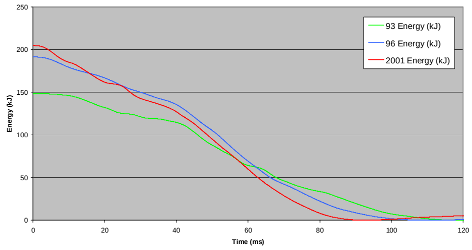

Figure 9. Barina ΔKE

DISCUSSION

The analysis of peak B-pillar longitudinal acceleration, Gx, showed an upward trend with increased test mass and also for newer vehicles. However, the regression analysis did not show any significant correlation with either YOM or mass of the test vehicle.

The peak Gx ranged from 40g to 17g while the time of max Gx was between 103msec and 48msec. However, the mean Gx and t_{max} for the vehicle categories studied covered a smaller range; 39g and 85msec for large cars, 31g and 90msec for medium cars and 33g and 79msec for small cars.

Similarly, there was no significant correlation between the time of peak Gx, t_{max}, and either YOM or mass.

When the data was broken into vehicle categories the results were not consistent across the categories.

Both Gx and t_{max} remained consistent for large cars while the medium cars had a reduced Gx while t_{max} remained consistent. Both these categories had a low number of results in the groupings, only 2 vehicles in some cases. Therefore, the results may not be representative.

When the small car category was considered it was found that Gx remained consistent while t_{max} reduced from over 80 msec to 73.8msec for the later models. This may indicate that the frontal structure on the small cars tested has become more rigid and does not crumple as quickly. Using the EuroNCAP small car results may assist with this analysis.

The lack of correlation and variation in both Gx and t_{max} could be due to limitations of the offset frontal test at 64 km/h. Offset test assesses performance of structure, i.e. how well passenger compartment retains survival space.

The offset test at 64 km/hr may result in vehicles bottoming out on the barrier prior to all the crash energy being absorbed by the frontal vehicle structure. Alternatively, this could indicate there have been only limited changes to the front vehicle structure to manage the crash energy.

This corresponds to research conducted by both the US IIHS and also NHTSA. In their 2001 study, the IIHS found no correlation between stiffness and offset structural performance of vehicles. Similarly, a 1999 NHTSA study on the US NCAP results for light trucks and vans (LTVs) found that during the 14 years of US NCAP frontal crash testing, on average, LTVs have become less stiff.

Additionally, the ANCAP crash tests have shown significant improvements in occupant protection as measured by the test dummies and also through analysis of the vehicle deformation.

The ANCAP crash tests have demonstrated that while the integrity of the vehicle passenger compartment has improved with reduction in intrusion the HIC and chest deflection measures have also reduced.

The analysis of 5 different models presented here has shown that the maximum seat belt loads varied between 4.7 kN and 7.8 kN for lap belts, and 4.9 kN & 7.7 kN for sash belts.

The maximum seat belt loads for each model varied from test to test without any trends for increasing or decreasing loads developing. It was expected that the seat belt loads would vary to compensate for any change in the energy management of the vehicle structure.

CONCLUSIONS

This paper reviewed crash tests measurements, driver side peak longitudinal acceleration, time of peak acceleration and driver seat belt loads from ANCAP offset frontal crash tests.

This analysis indicates that the occupant restraint system may still be the most significant factor in reducing serious head and chest injury.

While the analysis showed some trends, i.e. peak Gx increased with increased test mass, a regression analysis did not show any significant correlation between peak Gx and either time of peak acceleration or YOM. Therefore, this analysis does not indicate any significant changes to vehicle structures that affect the peak longitudinal acceleration measured at the base of the driver's B-pillar.

When individual vehicle categories are considered the small cars showed a decrease in time of peak acceleration with newer vehicles. A review of additional results of offset frontal crash tests on small vehicles, such as EuroNCAP tests, would assist with reviewing this position.

The analysis showed that while the dummy injury measurements have reduced there has not been a corresponding reduction in either 'B' pillar accelerations or seat belt loads.

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APPENDIX A

Table A1.
Right (Driver) B-pillar Peak Gx Measured during ANCAP tests

Vehicle YOM, Make and Model	Category	Test mass (kg)	Right (driver) B-pillar	
			Gx (g)	t_{max} (ms)
2001 Toyota Avalon	Large	1726	34.44	99.3
2000 Mitsubishi Magna	Large	1706	42.52	78.6
2001 Ford Falcon	Large	1792	34.07	79.4
2000 Holden Commodore	Large	1814	46.25	88.8
1997 Ford Falcon	Large	1823	42.24	78.1
1997 Holden Commodore [1]	Large	1857	-	-
1996 Mitsubishi Magna	Large	1707	34.70	79.89
1994 Ford Falcon [2]	Large	1798	43.22	86.9
1994 Holden Commodore [2]	Large	1825	37.90	93.8
2000 Toyota Camry	Medium	1655	37.52	95.5
1999 Daewoo Leganza	Medium	1650	24.58	101.1
1998 Mazda 626	Medium	1508	32.65	80.6
1999 Subaru Liberty	Medium	1665	40.44	74.6
1997 Toyota Camry	Medium	1635	34.45	90.3
1996 Honda Accord	Medium	1592	36.75	92.81
1996 Hyundai Lantra	Medium	1424	39.42	77.4
1995 Toyota Camry	Medium	1641	27.95	87.22
1994 Toyota Camry [2]	Medium	1630	28.40	102.5
1994 Subaru Liberty LX [2]	Medium	1415	31.25	83.9
1994 Subaru Liberty GX [2]	Medium	1450	28.90	89.1
1993 Hyundai Lantra [2]	Medium	1400	31.85	83.8
1994 Holden Commodore (4 cyl) [2]	Medium	1326	31.85	83.8
2002 Toyota Corolla	Small	1093	31.53	83.2
2001 Mazda 121 Metro	Small	1054	36.30	55.0
2001 Holden Barina	Small	1296	34.54	78.8
2001 Kia Rio	Small	1313	33.92	89.0
2000 Mazda 323	Small	1365	26.93	70.9
2000 Daewoo Nubri	Small	1520	26.74	65.8
1996 Honda Civic	Small	1342	36.89	99.27
1996 Nissan Pulsar	Small	1367	29.66	77.03
1996 Daihatsu Charade	Small	1162	28.74	82.37
1996 Nissan Micra	Small	1056	31.50	64.11
1996 Toyota Starlet	Small	1111	111.5	144.5
1996 Holden Barina	Small	1197	27.97	65.47
1996 Mitsubishi Mirage	Small	1111	32.15	70.94
1995 Daewoo Cielo	Small	1273	21.06	77.53
1994 Hyundai Excel [2]	Small	1240	23.56	88.2
1994 Ford Laser [2]	Small	1384	34.16	83.5
1994 Holden Barina [2]	Small	1062	36.61	80.5
1994 Toyota Corolla [2]	Small	1326	26.57	77.5
1993 Toyota Corolla [2]	Small	1321	31.95	85.5
1993 Hyundai Excel [2]	Small	1248	26.31	92.1
1993 Subaru Impreza [2]	Small	1332	30.84	98.9
1993 Mitsubishi Lancer [2]	Small	1233	31.65	61.9
1993 Honda Civic [2]	Small	1256	33.66	92.9
1993 Mazda 121[2]	Small	1091	25.29	46.7
1993 Ford Laser[2]	Small	1270	30.4	88.0
1993 Holden Barina [2]	Small	1059	27.84	64.9
1993 Nissan Pulsar [2]	Small	1348	35.79	84.1

Notes: 1. ‘-‘ denotes data was not available
2. 60 km/hr test